Observations Regarding Sediment Type and Compressional-Wave Velocity

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LONG-TERM GOALS

To enable realistic geoacoustic modeling given limited sediment properties information.

OBJECTIVES

The purpose of this research is to examine ODP sonic logs to determine if there are indeed consistent relationships between compressional-wave velocity (Vp) and certain sediment types. Geoacoustic models (Hamilton,1980) are widely used in the acoustical and geophysical communities to predict acoustic behavior in the upper several hundred meters of the sea floor. The basis for these models are regression equations that provide expected values for various sediment "geoacoustic" properties as they change with depth below the sea floor. A key element of geoacoustic models is the change in sound velocity with depth. Hamilton (1980) derived velocity/ depth functions for three sediment types (siliceous - S, terrigenous - T, and calcareous - C) based on empirical fits to field measurements (sonobouy data). The curves imply a correlation between sediment type and velocity to the extent that one can reasonably predict acoustic behavior in most ocean areas.

APPROACH

Since its inception, the Ocean Drilling Program (ODP) has collected more than 250 continuously logged velocity/depth profiles (logs) encompassing the full range of sediment types. Thus, the logs represent a far more comprehensive dataset than Hamilton (1980) used regarding sediment type and sediment velocity. The research summarized below is based on the evaluation of these logs.

WORK COMPLETED

Sonic logs were down-loaded directly from the publicly accessible electronic archive available through Lamont-Doherty Earth Observatory website. For uniformity, the logs were culled according to several criteria: preference was given to long over short spacing when more than one log was available at a site, processed over raw data, initial logs over re-entry logs (for freshest hole conditions), and uphole logs over downhole logs (for more constant logging speed). The culling process resulted in 256 logs corresponding to numerous ODP sites. The data for each log was then binned at one meter interval in order to create a uniformly sampled data set with a median Vp representing the readings (usually 5) within each bin. No data below 1000 m were used.

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All but 70 of the ODP logs were eliminated because they are extremely heterogeneous, very short, or exhibited large oscillations in sound speed. The remaining logs are relatively long (300 – 800 m) and uncomplicated, i.e., the best for making comparisons. This was done by overlaying the logs on a light table and sorting them according to fit. Eventually, the sorting process resulted in seven groups that are defined by arbitrary velocity ranges.

1) 1400 and 1500 m/s (no gradient)

2) <1500-*1700 m/s

3) 1550-1700 m/s

4) 1575-2140 m/s

5) 1650-2450 m/s

6) *1700-2600 m/s

7) > group 6

* extrapolated value

Each group is characterized by a "type log", i.e., generally a long, uncomplicated log that is easily represented by a line or "type curve." The velocity range for each group is arbitrarily based on the sound speed at 100 mbsf and at 600 mbsf for each type curve. Within each group, the fit of the logs to the type profile ranged from good to perfect. In all cases, the overall trend of a log had to match the trend of the type curve. How the fit was ranked (e.g., fair, good, etc.) depended on how much a log deviated on either side of the type curve. Frequently, only the upper few hundred meters of a log fit the type curve; the misfit at depth generally caused by changes in velocity gradient and/or the logs becoming too complex. Because modeling begins at the sediment-water interface, the lower portions of the logs that deviated substantially from the type curves were not used.

Some logs did not fit any group and some fell between groups. These logs were not used because they complicate but do not alter the fundamental observations concerning sediment type and velocity. The upper 60-100 m of the sediment column was not logged owing to the nature of the drilling process.

RESULTS

A frequency distribution (Fig. 1) shows that carbonate sediments make up all seven groups, but are concentrated in group 5. Terrigenous sediments occur in all but the fastest group, but are concentrated in groups 4 and 5. Siliceous sediments (diatom oozes and diatom-rich clays/muds) occur almost exclusively in groups 1, 2 and 3, but are overwhelmingly concentrated in group 3 (which also contains volcanic/terrigenous sediment). Only in the case of siliceous sediment does there appear to be strong justification for using a common velocity/depth function to model these sediments. The clustering of most of the terrigenous sediment in groups 4 and 5 indicates that the type curves for these groups provide reasonable curves for modeling terrigenous sediments. Although carbonate sediment is well represented in group 5, most of the carbonate falls in the other groups. Thus, the likelihood of successfully modeling carbonate sediments based on a single curve (e.g., Hamilton's C curve) is remote.

A plot of the type curves from this work with Hamilton's three sediment curves (Fig. 2) reveals significant differences in both fit and velocity. More importantly, (keeping Figure 1 in mind) most or all these curves (including Hamilton's) may describe either a carbonate or terrigenous sediment. Using Hamilton's C curve would be a good for modeling carbonate sediments that fit into group 6 or perhaps

group 5, but a poor choice for carbonates in the other groups. The question then, is how does one know which curve to use if the only information is that the sediments in a given area are carbonate or terrigenous? As noted, only in the case of biosiliceous sediments does there appear to be a solid basis for using a single velocity/depth curve. However, the velocities predicted by Hamilton's S curve are substantially higher than those predicted by type curve 3 (Fig. 2).

Although siliceous sediments dominate groups 1-3, the presence of carbonate sediments in these groups indicates that the low velocities and at times, uniform velocity gradients, are not necessarily determined by siliceous organisms. Moreover, the presence of entirely terrigenous and volcano-terrigenous sediments indicates that it is not biogenic components in general that account for such low velocity sediments. Also interesting is the observation that substantial decreases in diatom content (e.g., from 60-70% to 10-20%) had no visible effect on the Vp log. Indeed, at most drill sites the boundaries between lithologic units are frequently not associated with changes in the logs. Many of the boundaries, to be sure, mark relatively subtle changes (e.g., a decrease in carbonate content, a sandy silty clay rather than a silty clay etc.). However, even substantial changes (e.g., clay to claystone, ooze to chalk, etc.) are not represented by obvious changes in Vp owing to their transitional nature. Significant increases in Vp are usually related to major lithologic changes, e.g., chalk to limestone, turbidite sands/silts, debris flows, chert, etc.

IMPACT/APPLICATION

The results of this work demonstrate that the relationship between sediment type and sediment velocity is tenuous. The use of one velocity/depth function to describe a given sediment type is most applicable in the case of siliceous sediments and least applicable with carbonate sediments. Nevertheless, velocity/depth functions should not be abandoned. In many cases, they may provide acceptable representations of the velocity structure in a given areas, depending on how sensitive models are to velocity changes with depth.

TRANSITIONS

It is expected that the results of this work will find application within the acoustical and geophysical communities that use geoacoustic models for predicting the interaction of acoustic signals within the sediment column

RELATED PROJECTS

None

REFERENCES

Hamilton, E. L., 1980. Geoacoustic modeling of the sea floor, J. Acoust. Soc. Am., 68(5), 1313-1340.

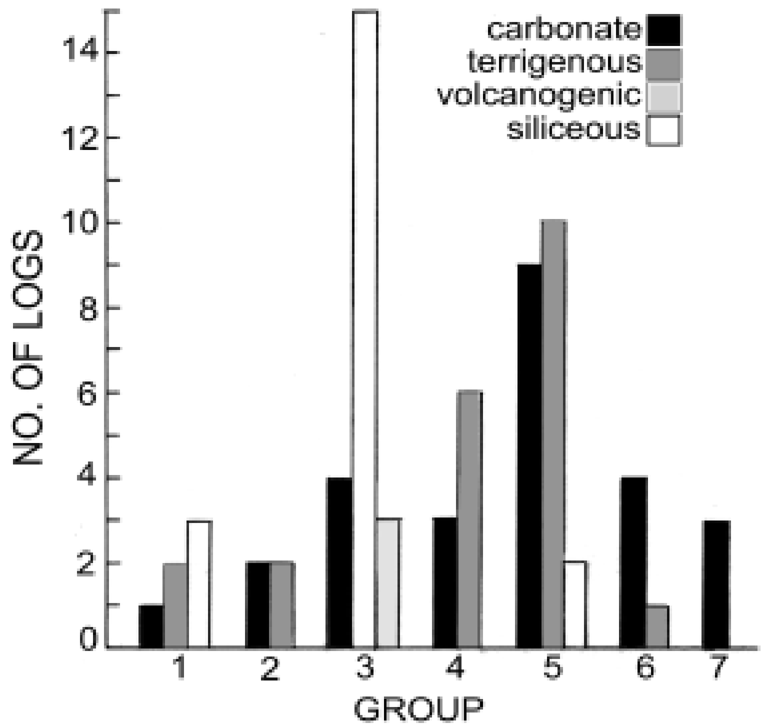

Figure 1. Distribution of sediment type by group.

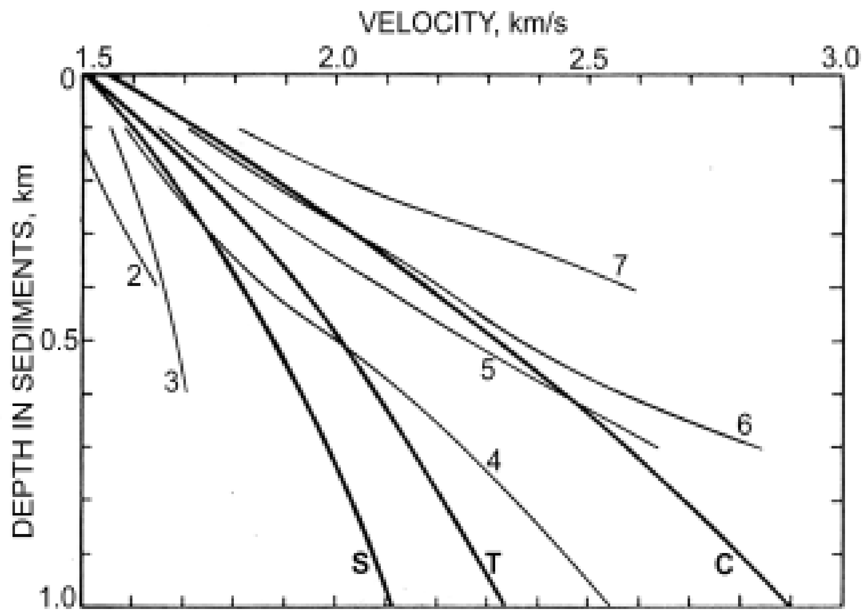

Figure 2. Compressional wave velocity versus depth in the seafloor for principal sediment types provided by Hamilton (1980): siliceous (S); terrigenous (T); carbonate (C). Curves 2-7 are type curves corresponding to groups 2-7 shown in Figure 1 and listed in text.